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THE HYDRO-ELECTRIC POWER COMMISSION
OF ONTARIO

INTERIM REPORT
ON
A PROPOSAL
TO
STANDARDIZE FREQUENCY
AT 60 CYCLES
FOR
THE SOUTHERN ONTARIO SYSTEM

NOVEMBER, 1946

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For some years the Commission has been interested in the possibility of adopting a standard frequency of 60 cycles for the Southern Ontario system and has been considering some of the problems associated with the conversion of the Niagara division from 25 to 60 cycles.

More recently, this question has received a great deal of public attention. Specific requests for information on the subject have been received from the Provincial Government, the Toronto Hydro-Electric System and the Ontario Municipal Electric Association.

The Commission's study to this date of the controlling factors of the problem is embodied in this interim report which it is hoped will be useful as a basis for discussion.

Historical

Before discussing the manner in which conversion of the Niagara division to 60 cycles might be carried out, it is desirable to deal briefly with the origin of 25-cycle frequency at Niagara Falls and to show why it has been perpetuated in the Niagara division of the Southern Ontario system.

When the Niagara Falls Power Company undertook its first major electrical power development at Niagara Falls, New York, in 1893, it recognized the importance of selecting a frequency which would be best suited to the requirements of its prospective customers and, with a view to obtaining the

most competent advice on this question, engaged an international board of consulting engineers, among whom were Professor George Forbes of England, and Dr. Coleman Sellers and Professor Roland of Johns Hopkins University. Quite independently a study of the problem was made by the Westinghouse Company, which foresaw the difficulties in supplying with alternating current both lighting (for which higher frequencies were preferable), and power service (for which lower frequencies were at that time preferred).

The Niagara Falls Power Company's engineers reached the conclusion that a frequency of 16-2/3 cycles would be the most satisfactory, having regard to the performance of motors and rotary-converters as then known and designed. The Westinghouse Company engineers, on the other hand, reached the conclusion that 30 cycles would be the most satisfactory frequency for power use and 60 cycles for lighting and other small installations. Ultimately a compromise was reached, the Niagara Falls Power Company selecting a frequency of 25 cycles - a frequency at which the Westinghouse Company was prepared to supply and guarantee the electric generators.

In view of the comprehensive study then given to this problem, it may be said that the selection of 25 cycles by the Niagara Falls Power Company had a sound technical background, based on existing knowledge in the art of electrical engineering at that time. It was quite natural, therefore, that when the power developments at Niagara Falls, Ontario, were undertaken a few years later they should be developed at 25 cycles. The

Canadian Niagara Power Company (in operation 1904) and the Ontario Power Company (in operation 1905) anticipated that the greater part of their output would be exported to the 25-cycle market in the State of New York, and the Electrical Development Company (in operation 1906) expected to transmit a large part of its output to Toronto, a distance of approximately 90 miles, which at that time was considered long distance transmission, for which the lower frequency was preferred.

In the intervening years between the construction of the Niagara Falls Power Company's first development (in operation 1896) and the initial operations of Hydro in 1910, advances in the art of electrical engineering overcame some of the initial obstacles in electric power applications but not to the point of materially affecting the relative status of the two frequencies. Having regard to the large amount of low price, 25-cycle power, which was already available at Niagara Falls, and the recognized advantages of low frequency for long distance transmission, it is believed that the decisions the Commission then made, to purchase blocks of 25-cycle power and later to purchase the generating plants, were well founded.

It is well also to remember that upon the basis of 25-cycle power being available in large amounts and at low cost, the Hydro enterprise rapidly attained an advantageous position. It built up an industrial centre second to none in Canada, and has continuously been several years ahead in the low cost of its residential and commercial service and in the use made of electricity by the citizens of Ontario.

Considering that the construction of the Queenston plant was undertaken when the world war of 1914-1918 was in progress and when demands on manufacturing facilities and finance were at a maximum, and having regard to the distances to which power would have to be transmitted, the Commission decided not to depart from the frequency of 25 cycles which had already been so well established.

In 1926, when the eastern power contracts were negotiated, the question of frequency again received consideration. Transmission of this power to the eastern limits of the Niagara system involved distances of approximately 230 miles in the case of Gatineau and nearly 300 miles in the case of Beauharnois. The transmission of large blocks of power over such long distances and at the voltage selected, 220,000 volts, was in the nature of a pioneer undertaking and again 25-cycle frequency was considered to have certain advantages for the Commission's operations.

The growth in load and changed conditions resulting from technical developments since that time have made it necessary again to review the situation to determine whether a change from 25 to 60 cycles in the Niagara division is desirable and practicable.

Advantages Claimed for Change to 60 Cycles

Some of the outstanding points in favour of the changeover are as follows:

(a) Improvements in the art of power transmission and the use of synchronous condensers for voltage regulation

have enabled utilities to transmit 60-cycle power economically in quantity over long distances. While voltage regulation and system stability problems are more severe at 60 cycles, previously placing this frequency at some disadvantage in the matter of transmission and distribution, this disadvantage is at least partly compensated for by the fact that voltage regulating devices (synchronous condensers and static capacitors) are less expensive at the higher frequency.

(b) Sixty cycles has become the standard of frequency for the North American continent and utilities both in the United States and Canada that previously used frequencies other than 60 cycles have largely changed to the 60-cycle standard, except in certain special cases such as heavy electrochemical, electro-metallurgical and steel mill loads. The adoption of 60 cycles as the standard frequency in Southern Ontario would permit the free interconnection of the Commission's systems with those of adjoining utilities in which this frequency is already accepted, with the consequent more efficient and more flexible utilization of the power resources.

(c) The Niagara division is in the process of being isolated into an island of 25-cycle power with attendant disadvantages such as a narrow purchasing market which will not permit the development, in the 25-cycle field, of the benefits of mass production now attained in the 60-cycle equipment field. Thus, as time goes on, Canadians in the 25-cycle territory will be placed in an increasingly disadvantageous position with

regard to obtaining newly-developed appliances manufactured by mass production methods.

(d) Modern 60-cycle lighting equipment is more satisfactory and more economical for factory, office, commercial and home use, particularly in the newer developments of fluorescent and other gaseous discharge type lamps. The same factor applies in the newer developments in radio, in the industrial applications involving electronics and a wide variety of new control devices.

(e) Manufacturers coming to Ontario to establish plants find it necessary to do one of three things: redesign their equipment for 25-cycle operation; install frequency changers; or establish their plants in 60-cycle territory.

(f) Consumers moving from 25 to 60-cycle territory or vice versa are put to expense and inconvenience due to the difference in frequency prevailing in Ontario, but in none of the other provinces of Canada.

As against these various items in favour of 60 cycles, there is, of course, the cost of making the changeover.

Present Situation Demands Decision For or Against Change

The Commission is now faced with the need of providing, from new generating sources, large amounts of additional power to meet the future requirements of Southern Ontario. A decision therefore must be made as to whether these new power supplies are to be developed at 25 or 60 cycles.

The question at this time is whether the present and future advantages of 60-cycle power are sufficiently great to

warrant the expense involved in the changeover of a very large 25-cycle system to a 60-cycle system.

What Would Changeover Involve?
A Three-Part Problem

The changeover problem consists essentially of three parts:

1. The supply of 60-cycle power by the Commission to the municipality;
2. The supply of 60-cycle power by the municipality to the consumer;
3. The changeover of the consumers' 25-cycle equipment.

These three problems need to be considered from the technical standpoint and from the standpoint of cost.

1. The problem of the supply of 60-cycle power in the 25-cycle area is not difficult technically and would present no serious economic problem, provided it could be accomplished stage by stage in accordance with a planned programme.

In converting existing 25-cycle generating stations little change would be required in the hydraulic turbines and associated equipment. However, the generators and much of their associated equipment would require complete rebuilding. The main step-up and step-down transformation probably could be reconnected, in some cases at very small expense. The major 220,000-volt transmission circuits from eastern sources (when the time came to convert them) would need to be augmented for 60-cycle service by the addition of one, perhaps two, new circuits. Synchronous condensers would have to be rebuilt and certain additional units would be required.

2. The problem of the supply of 60-cycle power by the municipality to the consumer likewise is not difficult technically, but economically it is more difficult to appraise because each municipality is an individual problem.

Within the municipal systems, step-down transformers would have to be reconnected or rewound, or in some cases replaced. The distribution facilities would have to be revised to provide generally smaller areas of distribution (lower capacity feeders) to compensate for the increased voltage regulation at the higher frequency. However, remedial measures might be adopted, such as the use of static capacitors or feeder voltage regulators, by which the construction of new distribution facilities could be held to a minimum.

With the exception of the older equipment, pole-type transformers could be used generally without any change. Meters could be rebuilt for 60 cycles.

3. The changeover of the consumers' 25-cycle equipment again offers no insurmountable technical problems but from the economic standpoint it presents the most perplexing problem. It can be considered in three aspects relating respectively to domestic, commercial and industrial consumers.

(a) Within domestic consumers' premises frequency conversion would require that most motor-driven equipment be rebuilt. Lighting and heating equipment would require little attention except where time-control elements exist, as for example on the more expensive electric ranges. Motors would require replacement on the larger motor-driven appliances and also on electric

clocks, though most of the smaller fractional horsepower motors are universal or can be adjusted for 60-cycle service. From a cost point of view, the refrigerator would involve the most expensive adjustment. In the case of the washing machine a change of motor would be needed, but where the mechanism is driven by a belt from the motor the change is a relatively simple one to make. Motors for workshops, water pumps, farm equipment, furnace blowers, oil burners, etc., would have to be changed to 60-cycle equipment.

(b) The same general conditions would affect the commercial consumer except that fluorescent lighting would require special attention. The degree and manner in which the commercial consumer would be affected would vary with the relative importance to him of his lighting, heating and motor-driven equipment. These in turn would vary with the character of the business - merchandising, restaurant, office building, etc.

(c) In the industrial field the change would be more complicated and problems would vary with the type of enterprise. In simple cases, motors and their controls would be replaced either with new or rewound equipment. It is anticipated that a certain proportion of the motors could be satisfactorily rewound for 60-cycle service. In more complex cases, revisions would be required in motor mountings, drives or gearing, and in the control equipment. The cost of changeover would be relatively high in modern factories using a multiplicity of individual motor drives and the problem would be more difficult where definite speeds are a prime factor in the operation of

the equipment. In difficult cases there would, of course, be the possibility of obtaining the advantages of 60-cycle service for lighting, etc., and of using for a few years frequency-changers for a proportion of the motor load. Mobile frequency-changers in various capacities would no doubt be an important technical tool in the changeover technique.

Looking Ahead

With reference to the foregoing three-part problems and before considering the programme for the main steps in changeover procedure, the following points should be kept in mind:

1. As time goes on the benefits to be derived from a change to 60 cycles will be augmented rather than lessened due to advances in the art of electricity utilization which will lead to an increase in the number of appliances and devices placed on the market for use at 60 cycles.

2. It is considered unsafe to assume that advancements in technique will in any way reduce the cost of the changeover or in any way reduce the ultimate necessity for it.

3. The cost of making a conversion will not decrease but on the contrary will undoubtedly increase with each passing year. Such increase will be occasioned, not only by the progressively greater number of consumers that will need to be converted, but by the constantly increasing cost of converting each individual consumer as the fields of application of electrical energy expand. Consider the domestic consumer, for example; the Commission estimates that it would have cost an

average of $48.90 to convert each domestic consumer under conditions prevailing in 1944. This figure may be compared to the Commission's estimate of $75.75, which is the figure it is estimated will apply in Ontario in 1950, under the labour and material conditions which it is assumed will then prevail.

In this connection it may be pointed out that when Great Britain delayed its programme of frequency standardization it was found that the cost of changeover increased year by year, as new load developed at non-standard frequencies, until final costs, when the change was eventually completed, were many times initial estimates.

Main Steps for Changeover Procedure

The main steps of the procedure entailed in the changeover can be enumerated as follows:

(1) A logical, economic plan would be developed for the initial steps in a more comprehensive programme, selecting those areas most conveniently situated to receive 60-cycle service.

(2) In these areas an interim programme would be developed, within the limitations of the flexibility existing among the presently available generating resources, pending the completion of new 60-cycle generating stations.

(3) All new generating stations would be designed and constructed for 60-cycle service and as these new sources became available the conversion programme would be expanded, releasing existing 25-cycle capacity to take care, temporarily, of growth in the 25-cycle areas.

(4) As the conversion programme proceeded and more 25-cycle capacity was released, the generating equipment would be changed to 60-cycle and further 25-cycle areas converted. This would continue to a point where the remaining 25-cycle equipment provided capacity sufficient for those industrial loads retaining 25-cycle service, with reasonable provision for service security and growth.

Flexibility with Respect to Timing

Before presenting the overall costs of a complete frequency changeover it is necessary to emphasize the desirability of ensuring flexibility in any programme considered. Technically and economically such flexibility can be arranged within the general programme of conversion.

Apart from the question of costs, economic aspects involve the consideration that frequency changeover is a project that will use many millions of man-hours of labour. This may be beneficial or the reverse, depending upon the timing of the programme. It would not be beneficial if competition for skilled labour made such labour less available for the completion of more important social services. It might on the other hand be very beneficial if, being started, it could be speeded up should economic depression or widespread unemployment threaten.

We may further note that the programme does not contemplate that all consumers would be changed to 60 cycles, as 25 cycles is still preferred for large slow-speed motor applications, for certain arc furnace applications and for heavy

electric traction. Some 350,000 kw of this type of load is to be found in the heavy industries in the Niagara district and the steel mills in Hamilton, which could readily be supplied from existing Niagara River generating plants.

Costs of Frequency Changeover

The figures presented in the following table include the estimated cost of rebuilding existing generating equipment (exclusive of the 350,000 kw in the Niagara River plants retained at 25 cycles to supply heavy industry in the Niagara Peninsula), the provision of the necessary additional transmission and distribution facilities from the generating sources to the ultimate consumers and the conversion of consumer equipment - all estimated on a conversion period of fifteen years:

Changeover Cost for	Basis 15 years
1. Generating and transmission equipment	$ 47,412,000
2. Municipality-owned distribution	35,300,000
3. Rural distribution	4,400,000
4. Domestic consumers	46,000,000
5. All consumer load other than domestic	62,200,000
Total Cost	195,312,000

The Commission has also estimated the cost of conversion on a twenty-year changeover basis. The cost remains substantially the same for the first item in the above table

but is increased somewhat for the remaining items. The estimated increase in cost should a twenty-year period be preferred to a fifteen-year period amounts to a sum of about $9,000,000.

While it is evident that very large sums of money are necessary for the complete programme of conversion, it should be remembered that the expenditures would be made over a period of years and integrated into the existing cost structure. Also, it is anticipated that a certain proportion of the expenditures could be written off against existing reserves, thus reducing the effect upon the cost of power.

It may also be stated that it is estimated that over 95 per cent of the total money expended for the changeover would be spent in the Province of Ontario for labour and equipment.

Financing the Cost of Changeover

After a study of different methods of meeting the costs of the project it was decided not to present any detailed methods before discussion with all parties concerned.

However, it is believed that the financing of the total project can be so arranged over a period of years (20 years is suggested) that there need not be any new debentures issued by the Commission specifically for this purpose. This could be made possible by the use of existing reserves, augmented by certain charges in the cost of power.

It is difficult to estimate accurately the effect upon the present rate structure of a complete changeover such as is outlined in this report, because of the many variable

factors and the extended time period involved. However, the plans considered by the Commission would permit of such a programme being executed and financed so as not to increase the wholesale power rates to municipalities under normal conditions more than 5 per cent on the average over 1945 rates.

The Work of Changing Equipment

The cost of changing consumers' equipment from 25-cycle to 60-cycle operation in homes, farms, commercial establishments, industry, etc., will largely depend upon the efficiency of organization. To keep such changeover costs to a minimum the Commission would require a special engineering organization, including field and shop crews, which could make conversions in predetermined areas with dispatch and at minimum cost. With such an organization it would be possible to salvage the maximum of material and equipment and by careful preparation and teamwork it should also be possible to reduce to a minimum the inconvenience to consumers entailed in changing their service and equipment.

The Commission would also be prepared, upon request, to undertake the engineering and/or the actual construction work of changing the distribution systems within municipalities where the normal staff complement is insufficient to handle the changeover.

Possible Initial Programme

A possible initial changeover programme is one based upon the assumption that all future generation will be installed at 60 cycles, that new 60-cycle power will be provided as

quickly as possible, and that sufficient load will be changed over from 25 to 60-cycle operation to enable new 60-cycle power to be absorbed under some practicable basis of distribution.

Such a programme could be undertaken without committing the Commission at this date to any rigid time schedule for the complete changeover in the Southern Ontario system of all 25-cycle power (other than that to be reserved for the 25-cycle industrial loads in the Niagara Peninsula - 350,000 kw).

A decision to discontinue the installation of new 25-cycle generating capacity in Southern Ontario would require that the Des Joachims development be constructed for 60-cycle service and a programme of conversion initiated by which the system load growth could be supplied from facilities originating at that point. However, this would not mean that new loads, wherever they appeared in the system, would be supplied at 60 cycles, for although it would be desirable to supply all new consumers at the higher frequency and thus avoid incurring the cost of later conversion of these new consumers, to do so would result in an uneconomic duplication of transmission and distribution facilities.

This programme would require the initial conversion of the equivalent of one year's load growth, which, in the 25-cycle Niagara division, is estimated to be 37,000 kw (50,000 hp). In the succeeding years the conversion of the annual load growth in the remaining 25-cycle area would be required.

The effect of such a programme on the Commission, the municipalities and the consumers may be briefly summarized as follows:

The Commission would install new generating capacity at 60 cycles, with new 60-cycle high-voltage transmission and main transformation at receiving terminals. Additional transmission facilities would be required at 60 cycles, but this would be offset to some extent by the saving in step-up and step-down transformation cost. By combining existing subtransmission lines with certain new construction 60-cycle power could be made available within a selected area at the points of delivery to the municipalities involved.

The initial programme of conversion could be devised in almost an infinite variety, depending on the area selected for a progressive changeover. Detailed study has been completed for one such programme, that considered to be most economical and most convenient from a technical viewpoint, and for this programme the total cost, up to the time when the Des Joachims development is fully loaded, has been estimated at $45,000,000.

It should be noted here that this figure includes all costs incidental to frequency conversion from generator to consumer, but does not include those expenditures normally required to maintain supply at 25 cycles. It is based on conditions estimated to exist in the year 1950; in other words, material and labour costs and the amount of equipment considered are estimated as being those likely to apply in that year.

The costs of consumer conversion used in the above estimate relating to the initial step are based on the following average estimated costs per consumer as of the year 1950:

Domestic consumers	-	$ 75.75 per consumer
Commercial consumers	-	127.80 per consumer
Rural consumers	-	75.40 per consumer
Industrial consumers	-	36.00 per connected hp.

Conclusion

Considerable study has been made of the engineering and economic aspects of the proposal to adopt a standard frequency of 60 cycles for the Southern Ontario system. There are no insurmountable engineering difficulties involved and there would be marked advantages in having a standard frequency of 60 cycles.

The problem is whether the present and future advantages of 60-cycle power are sufficiently great to warrant the expense involved in the changeover of a very large 25-cycle system, today totalling 1,000,000 kw of generating capacity (excluding 350,000 kw to be retained for 25-cycle industrial operation).

The Commission believes that the proposal is entirely practicable from a technical viewpoint and has prepared this interim report as a basis for consideration and discussion of the technical and other aspects of the problem by all parties concerned.